Pairing Energy Density Functiona in Finite and Infinite Systems

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UNEDF pairing is very important: which paring?

Volume pairing or surface pairing? $\eta = 0$ or $\eta = 1$?

α ?

$$V_{nn}(\mathrm{r}_1, \mathrm{r}_2) = V_o(1 - \eta \left(\frac{\rho(r)}{\rho_0} \right)^{\alpha})\delta(r_1 - r_2)$$

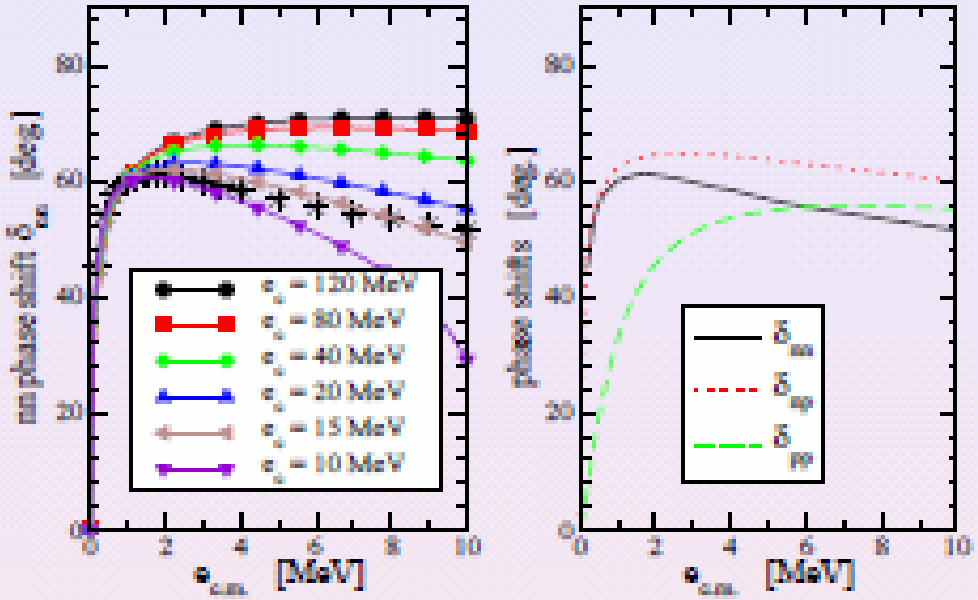
Realistic two-body interaction (AV18) ⟹ Isospin dependence of Pairing Interaction

Collaborators:J. Margeron (Orsay/Aizu), K. Hagino(Tohoku)

J. Margueron, H. Sagawa, and K. Hagino
Phys. Rev. C **76**, 064316 (2007) and to be published

Free interacion V_0

k_c and v_0 are adjusted so as to reproduce the low energy phase shift.



e_c (MeV)	a_{nn} (fm)	r_{nn} (fm)	α (fm)	V_0 (MeV.fm^3)	V_0^* (MeV.fm^3)	V_0^∞ (MeV.fm^3)
120	−12.6	0.75	−0.55	−448	−458	−481
80	−13.0	0.92	−0.66	−542	−555	−589
40	−13.7	1.30	−0.91	−746	−767	−833
20	−15.0	1.83	−1.25	−1024	−1050	−1178

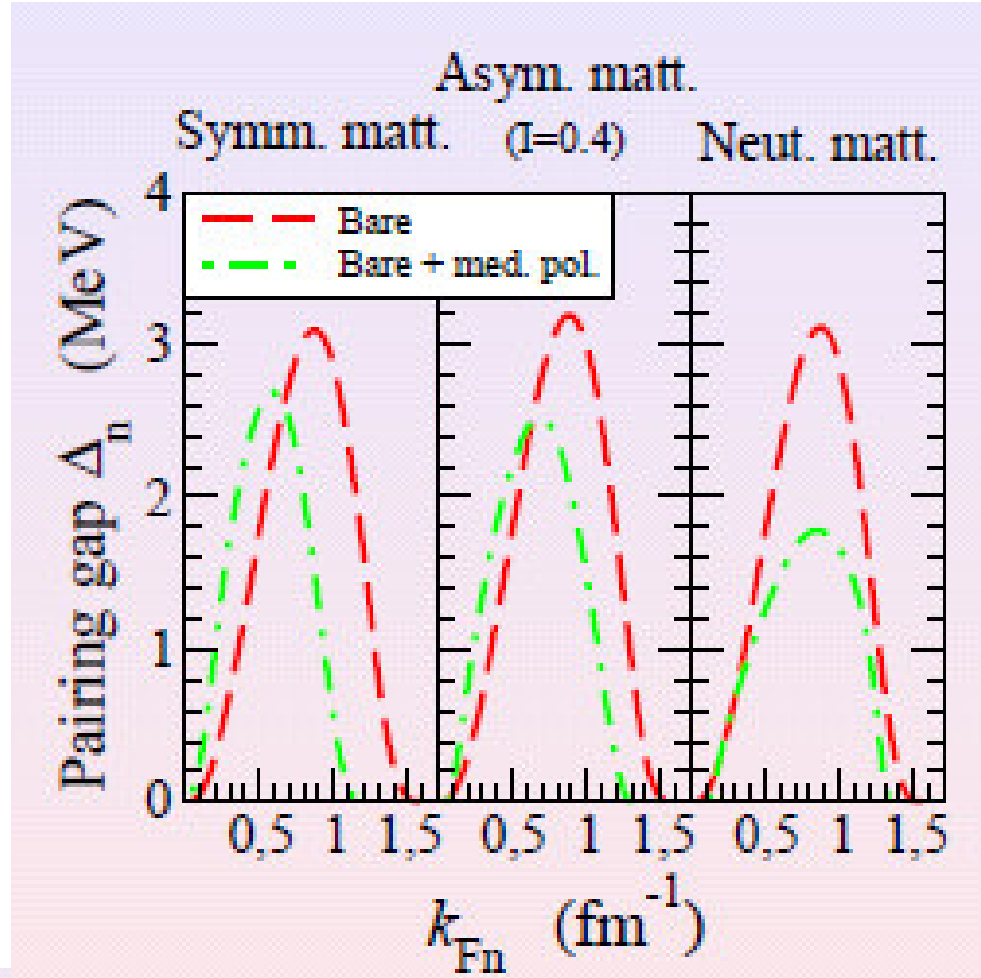
$a_{nn} = -18.5\text{fm}$

unitary limit

Nuclear matter calculations by Cao et al.

Phys. Rev. C74, 064301(2006)

interaction	E_c (MeV)	η_s	α_s	η_n	α_n	η_2
IS+IV Bare	40	0.664	0.522	1.01	0.525	0.0
IS+IV Induced	40	1.80	0.27	1.61	0.122	0.8
IS Bare	40	0.664	0.522	0.664	0.522	0.0



$$\langle k|V_{nn}|k'\rangle = \frac{1-P_\sigma}{2} V_0\, g[\rho_n,\rho_p]\, \theta(k,k')$$

The density dependent term is $g_\tau = g_\tau^1 + g^2$ with,

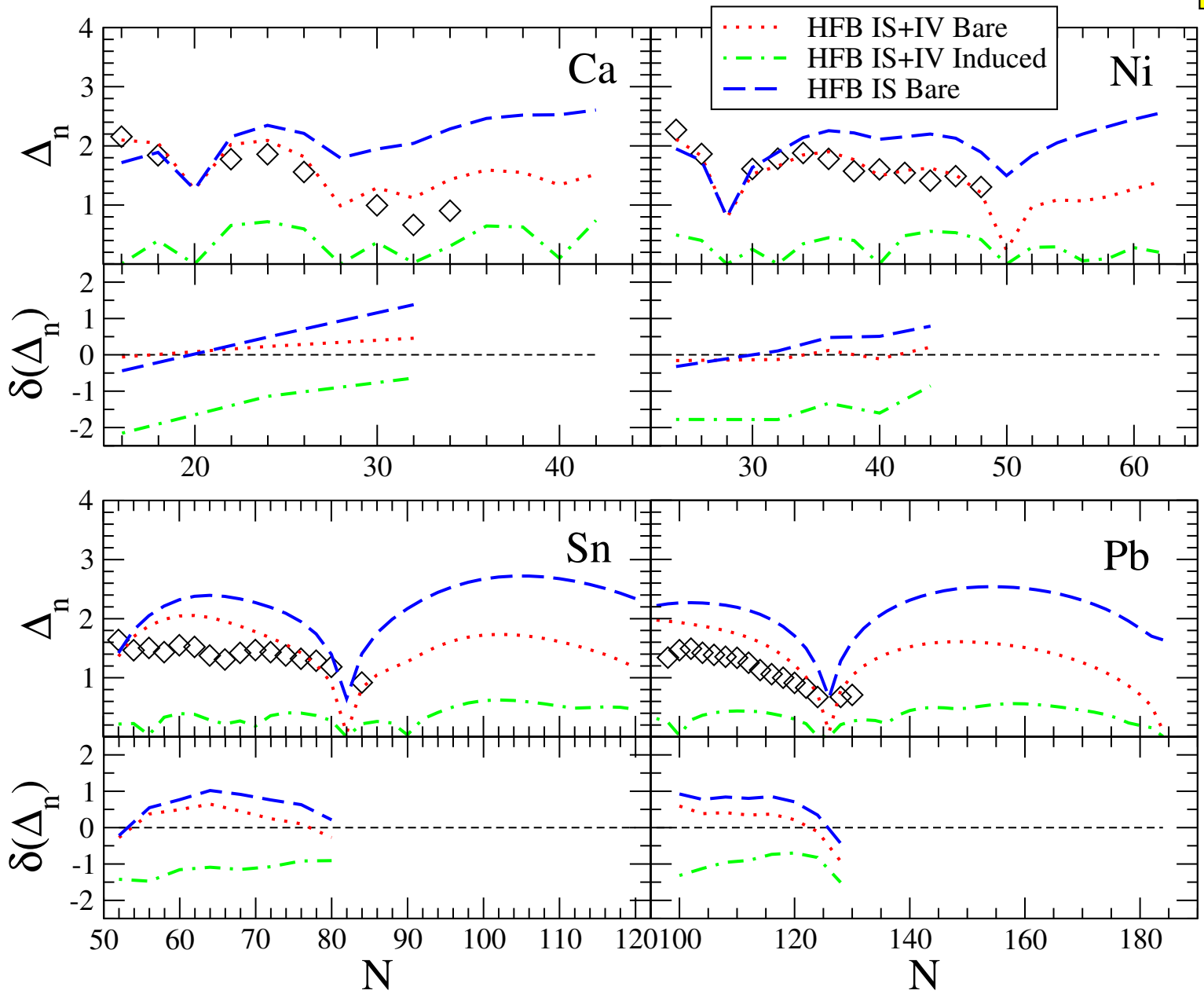
$$\begin{aligned} g_n^1[\rho,I] &= 1 - f_s(I)\eta_s\left(\frac{\rho}{\rho_0}\right)^{\alpha_s} - f_n(I)\eta_n\left(\frac{\rho}{\rho_0}\right)^{\alpha_n}, \\ g_p^1[\rho,I] &= g_n^1[\rho,-I] \text{ due to isospin symmetry}, \\ g^2[\rho] &= \eta_2\left[\left(1+e^{\frac{k_F-1.4}{0.05}}\right)^{-1} - \left(1+e^{\frac{k_F-0.1}{0.05}}\right)^{-1}\right], \end{aligned}$$

and with $f_s(I) = 1 - f_n(I)$ and $f_n(I) = I$.

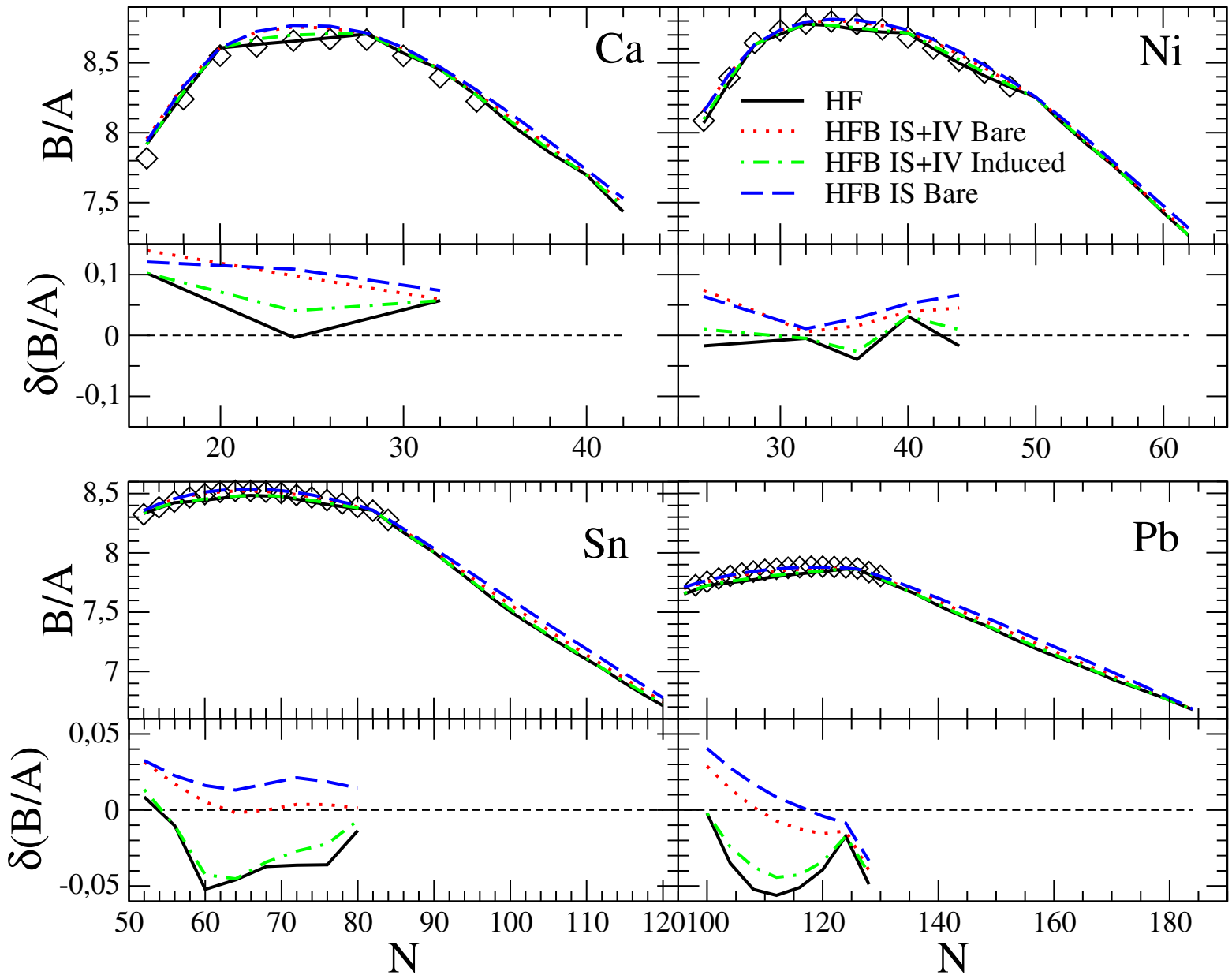
$$I = \frac{N-Z}{A}$$

HFB for semi-magic nuclei

SLy4

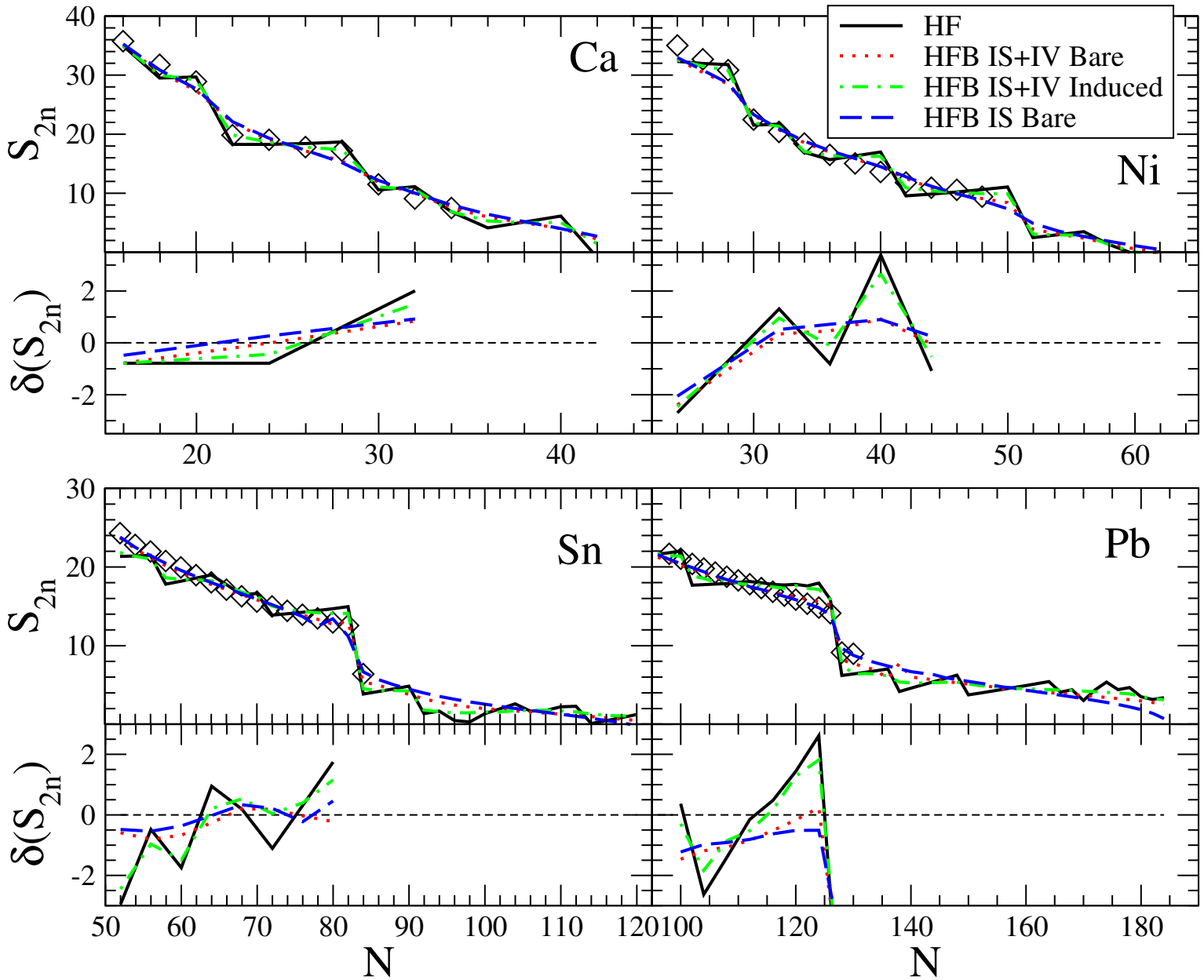


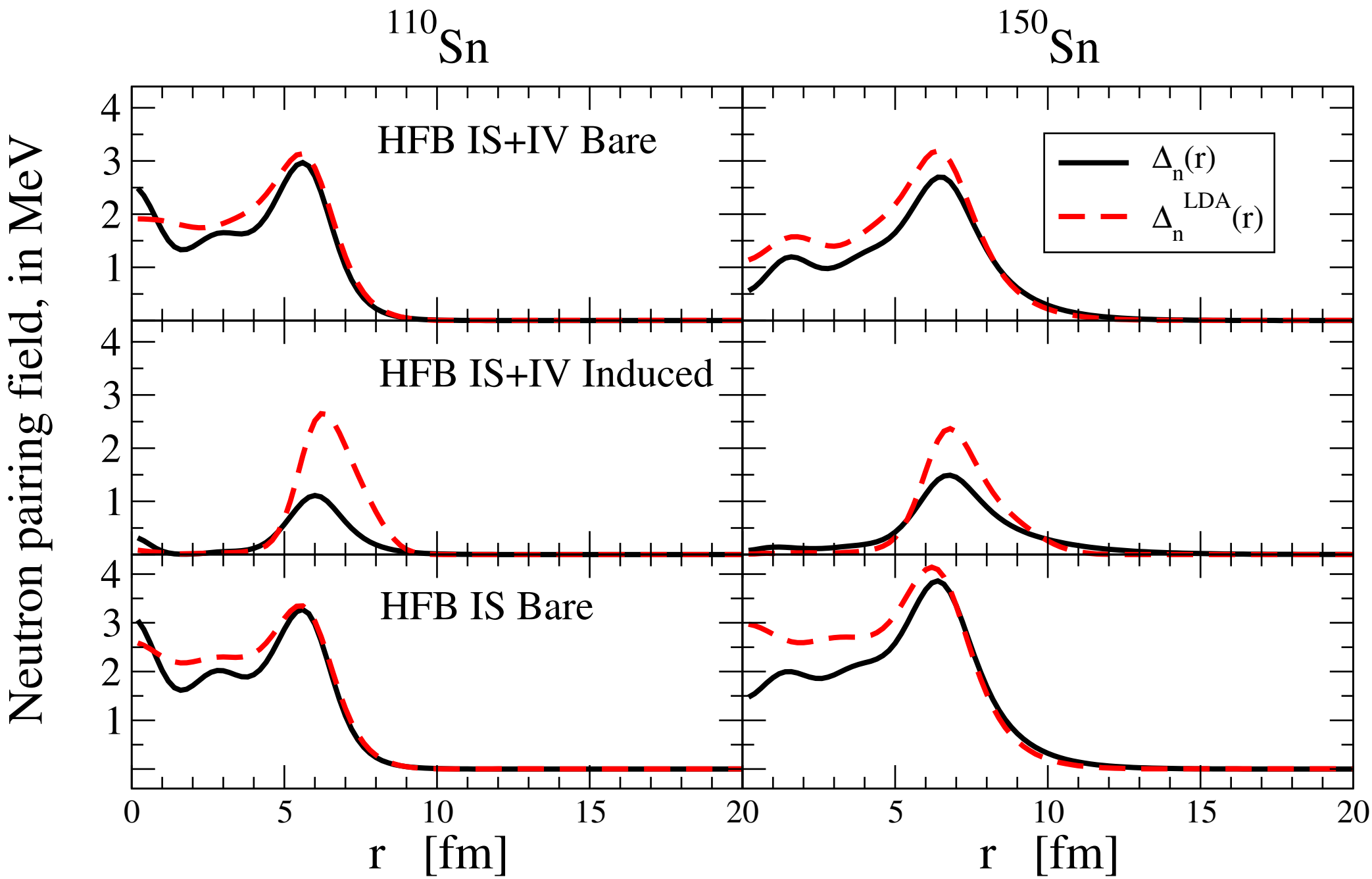
Binding energy

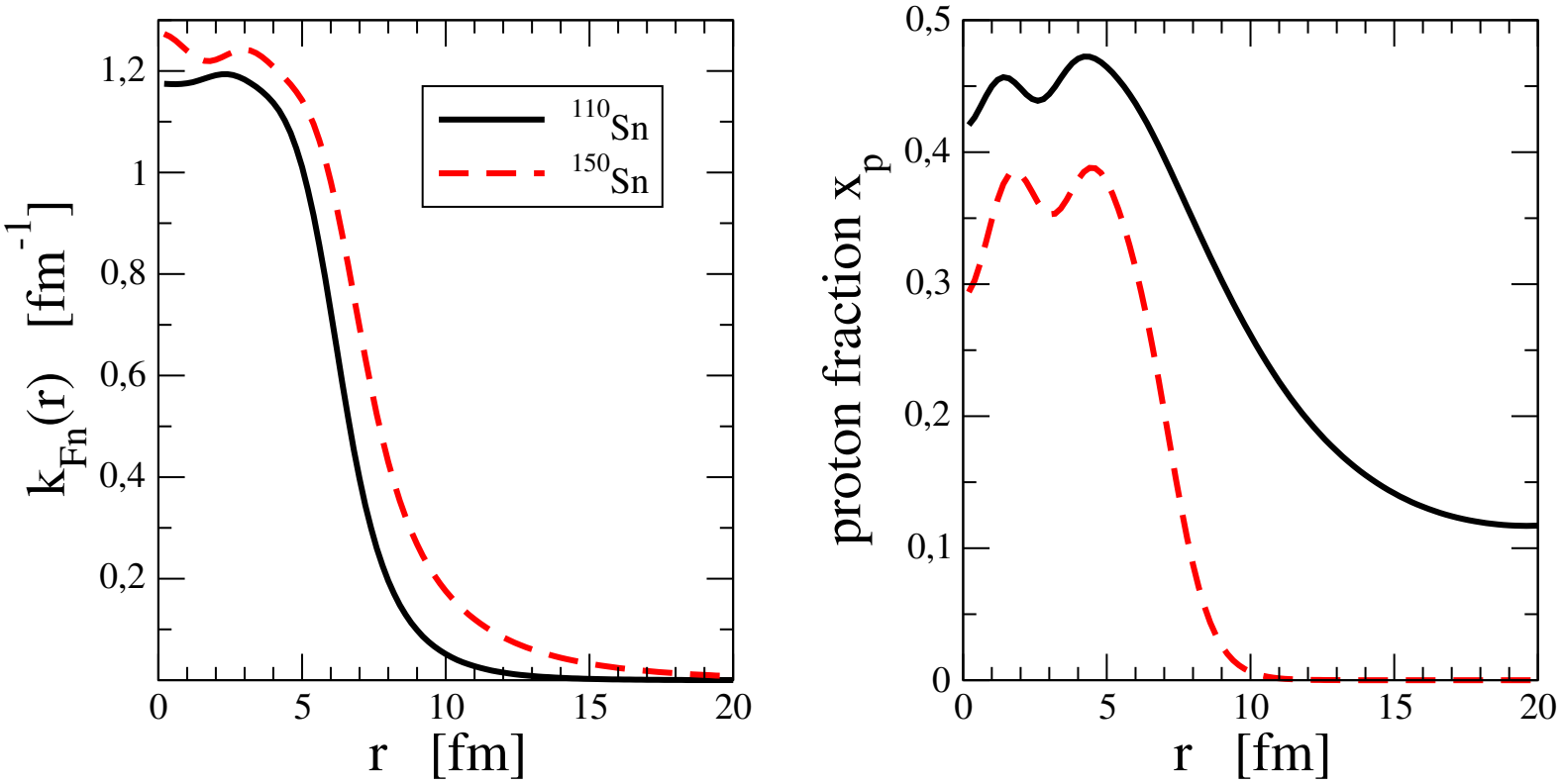


$\delta(B/A)=B_{HFB}/A-B_{exp}/A$

Two neutron separation energy




^{110}Sn
^{150}Sn
HFB IS+IV Bare
HFB IS+IV Induced
HFB IS Bare
$\Delta_n(r)$
$\Delta_n^{LDA}(r)$
Neutron pairing field, in MeV
r [fm]
r [fm]
0
5
10
15
20
1
2
3
4


1,2
1
0,8
0,6
0,4
0,2
0
5
10
15
20
$k_{Fn}(r)$ [fm^{-1}]
r [fm]
^{110}Sn
^{150}Sn
0,5
0,4
0,3
0,2
0,1
0
proton fraction x_p
r [fm]

In Ref.[11] Dobaczewski, Nazarewicz, Reinhard, Nucl. Phys. **A693**, 361 (2001)
if $\alpha_s \lesssim 0.5 \rightarrow$ pathological behavior of the densities. $\eta = 1$

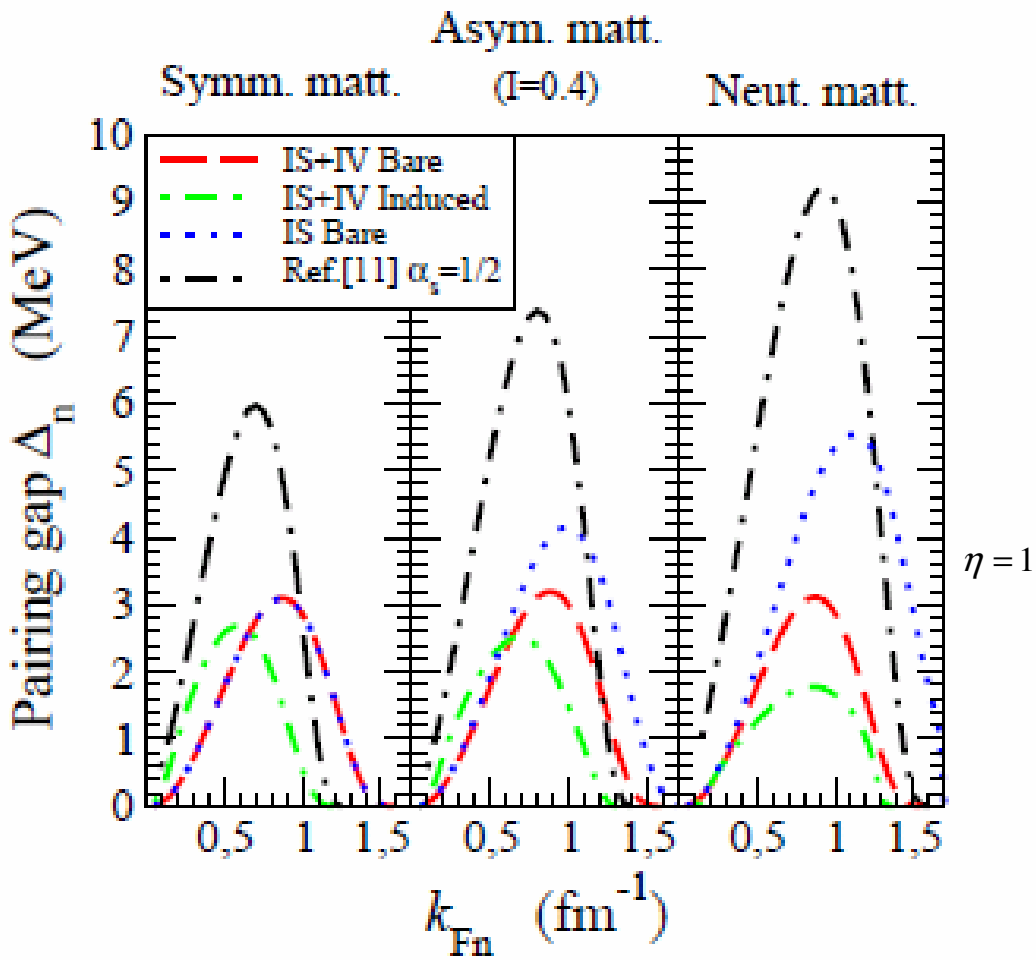


FIG. 5: (Color online) Pairing gaps in uniform matter obtained from the solution of the BCS equations with the pairing interactions IS+IV Bare, IS+IV Induced, IS Bare and the isoscalar interaction of Ref. [11] with $\alpha_s = 1/2$ and $\eta_s = 1$. Notice that the results of IS+IV Bare is identical to those of IS Bare in symmetric matter. See the text for more details.

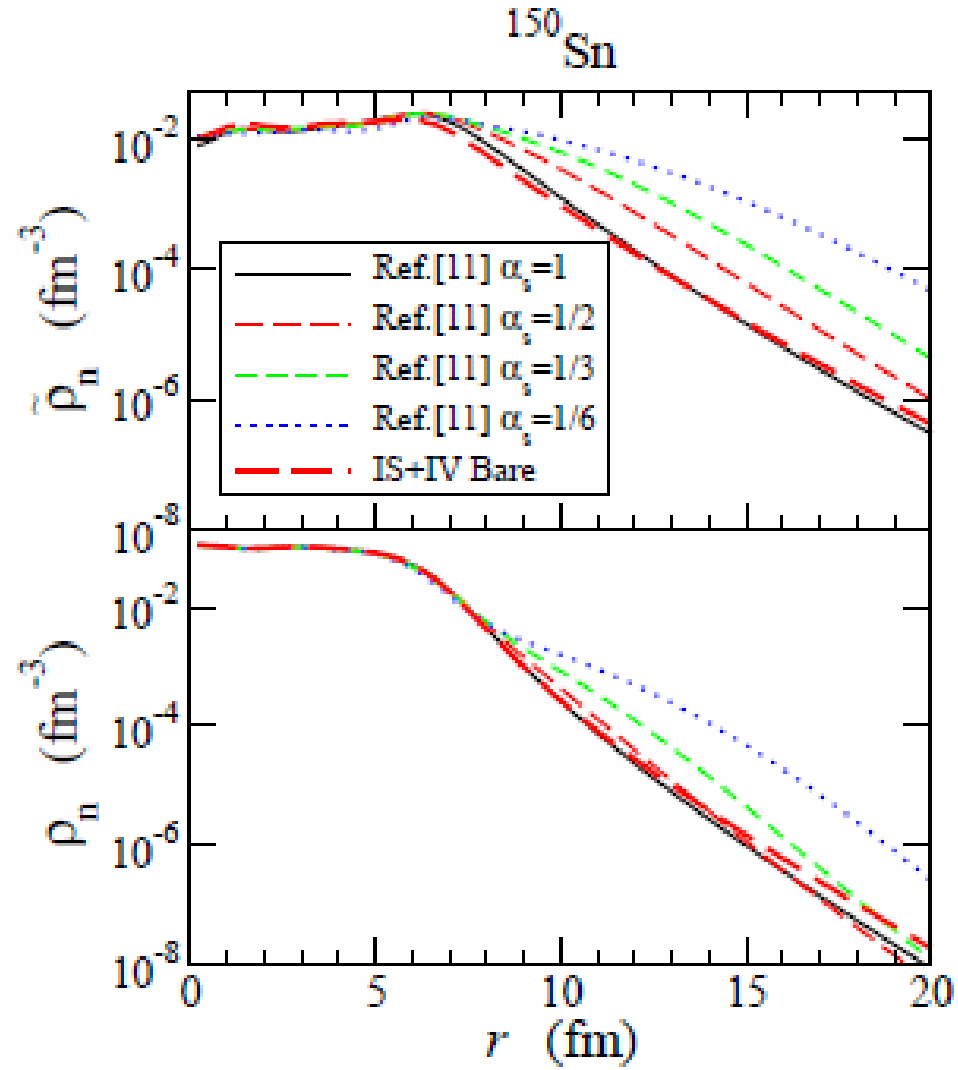


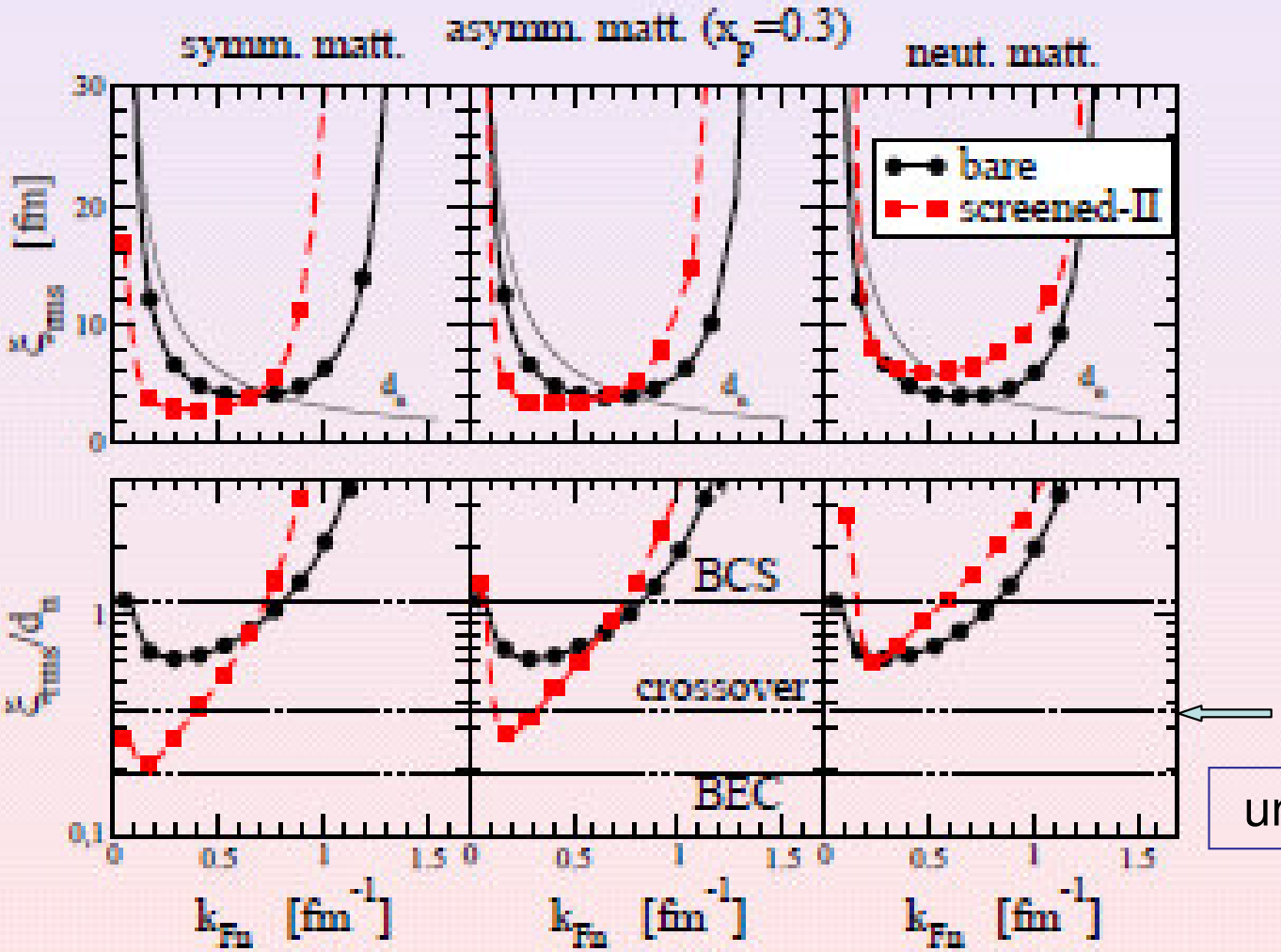
FIG. 6: (Color online) Comparision of particle and pairing densities for the nucleus ^{150}Sn obtained with several sets of interaction in Ref. [11] and with the IS+IV Bare interaction. See the text for more details.

BCS-BEC crossover

$$\xi_{\rm rms} = \int_0^\infty dr r^4 |\Psi_{\rm pair}(r)|^2 \text{ and } d_n = \rho_n^{1/3}$$

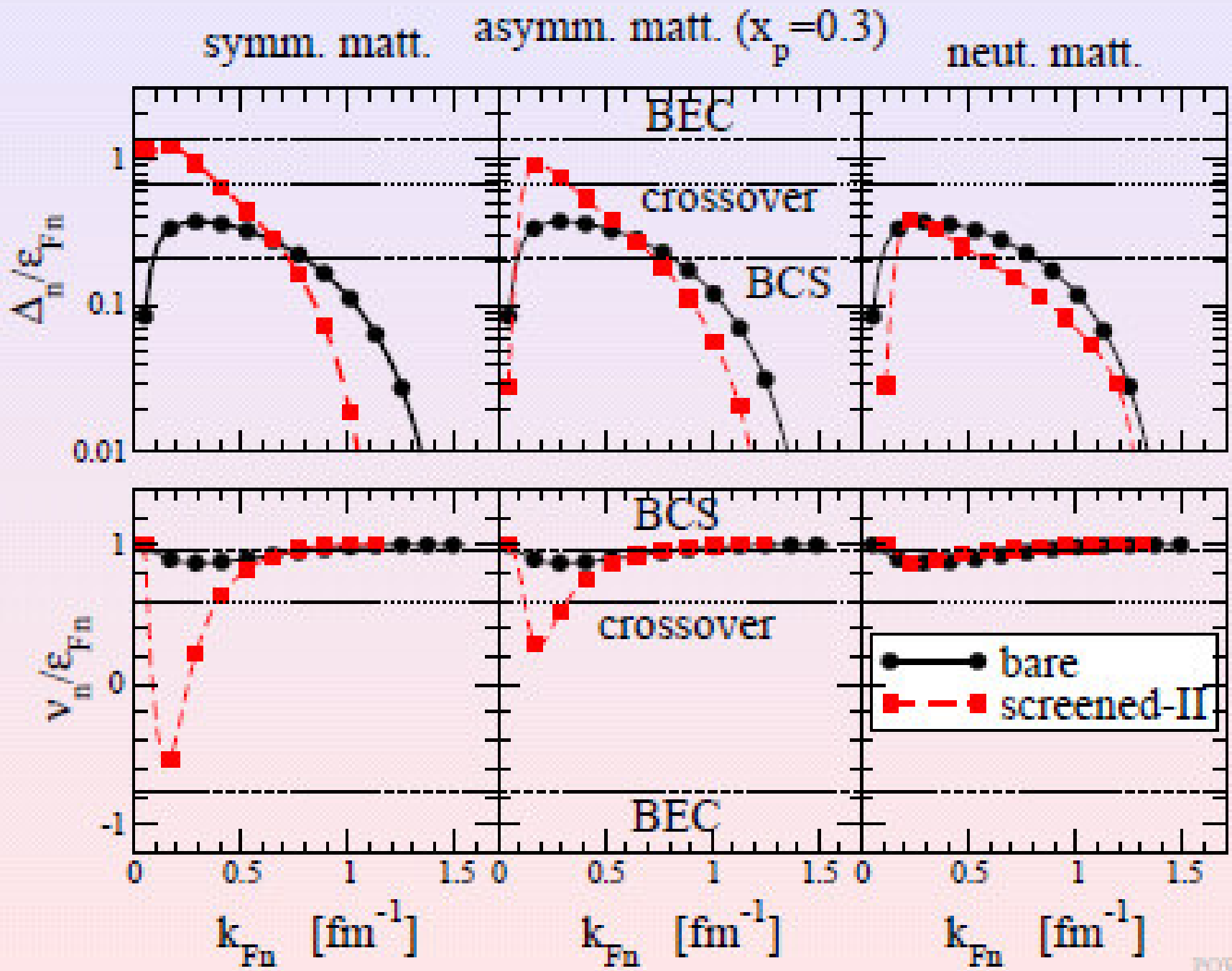
correlation length

order parameter



unitary limit

BCS-BEC phase-diagram and pairing interactions



Summary

1. Realistic two-body interaction gives:

   IS part ➡ mixed-type pairing

   IV part ➡ volume-type paring

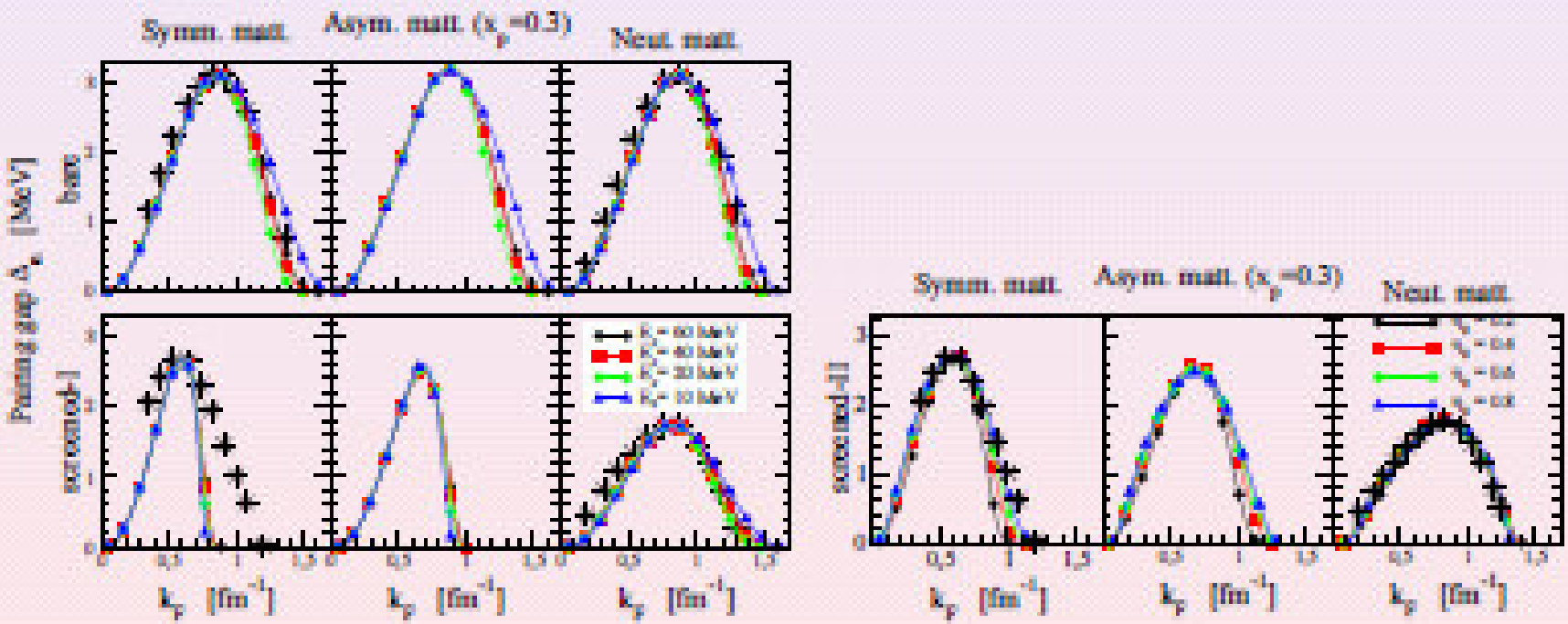
2. Importance of IV part in neutron-rich nuclei
3. Future application to excited states (QRPA)
4. BEC-BCS cross-over in nuclear matter
5. Medium effect in finite nuclei is consistent with that of nuclear matter?

Pairing gap in uniform matter obtained from microscopic treatment based on the realistic N-N interaction

Cao, Lombardo, Schuck, PRC 74, 064301 (2006)

Result of the adjustment :

$g = g_1$ $\qquad$ $g = g_1 + g_2$

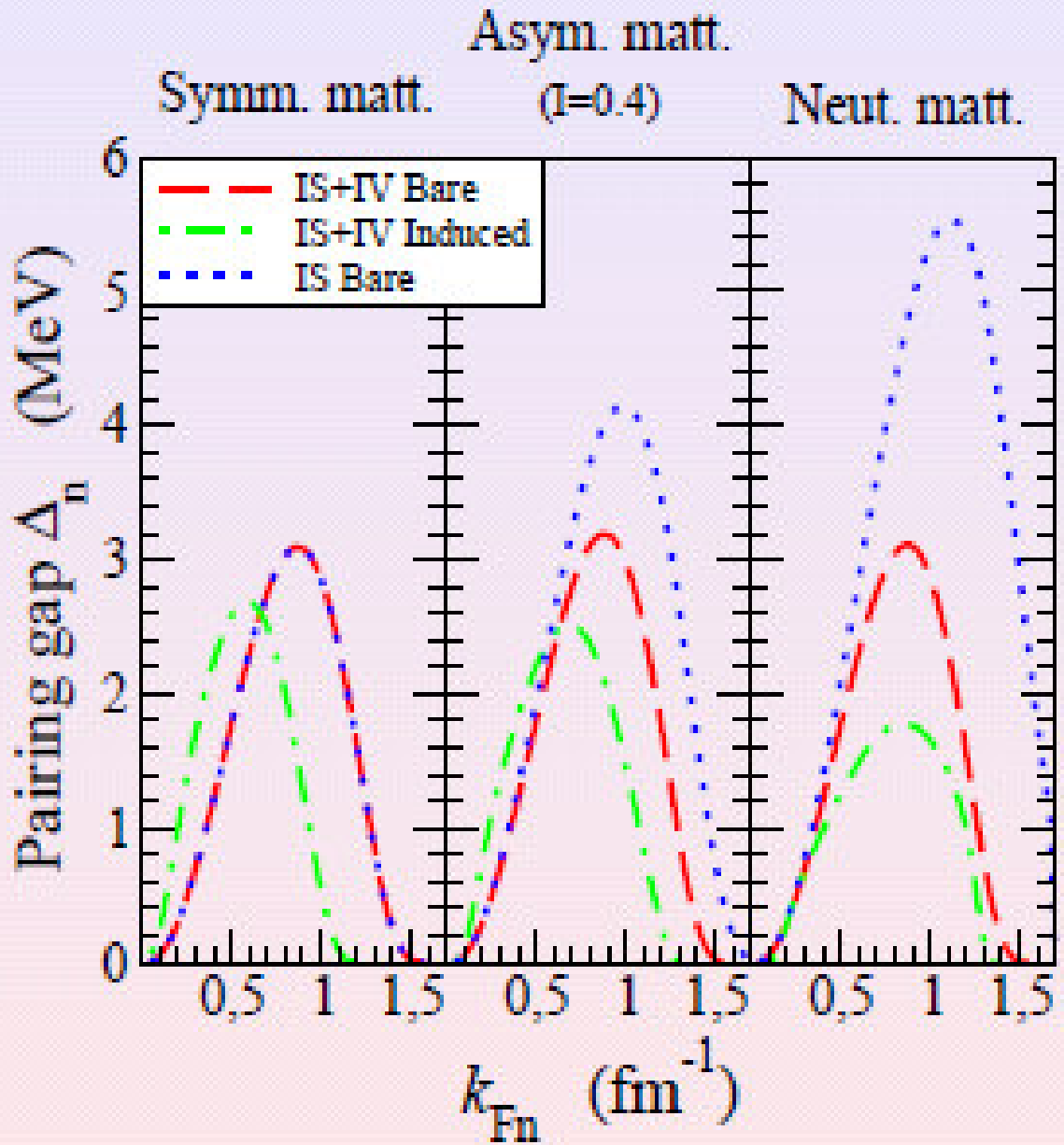


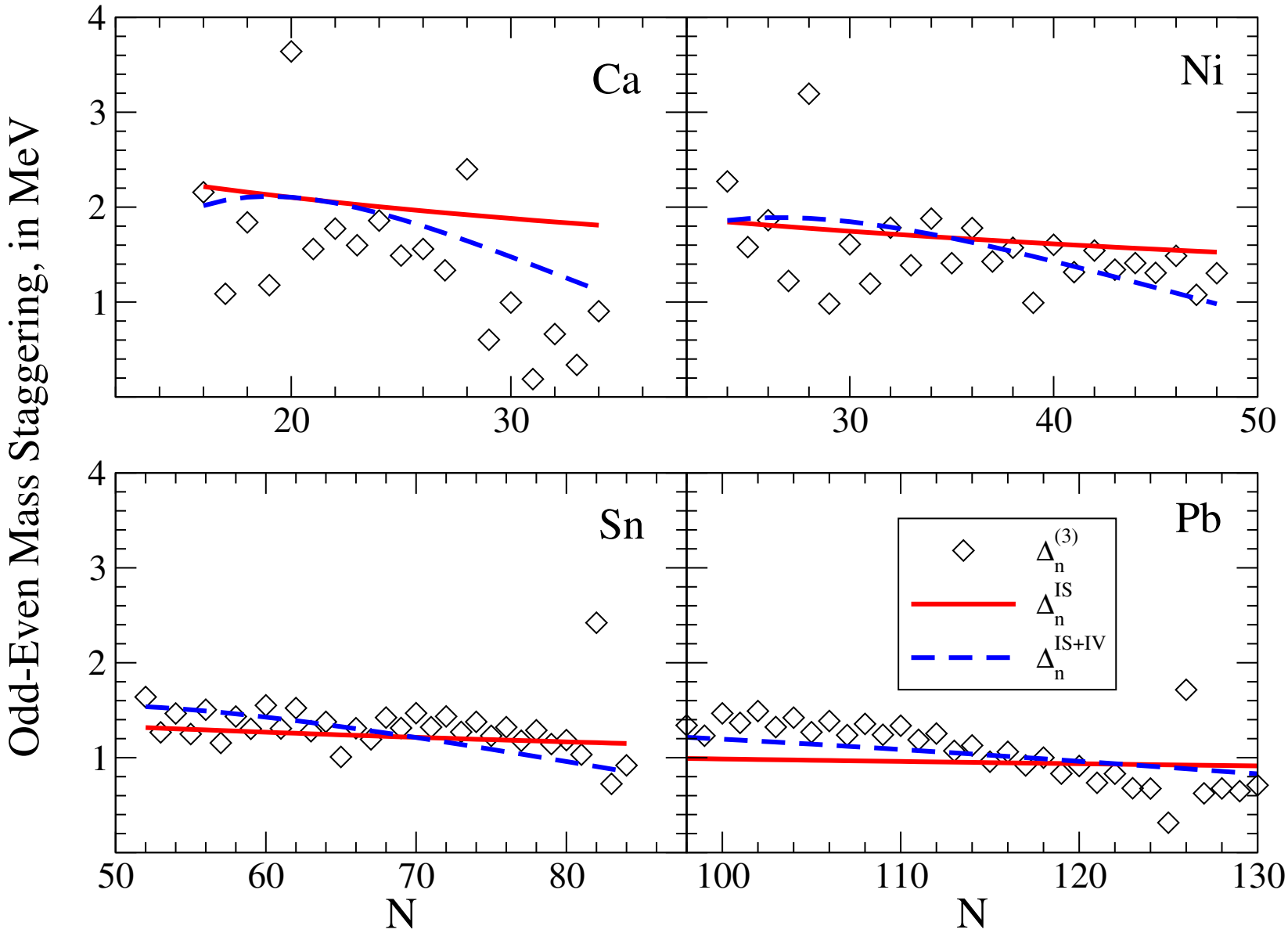
Neutron Fermi momentum k_{Fn} : $\rho_n \equiv k_{Fn}^3/3\pi^2$.

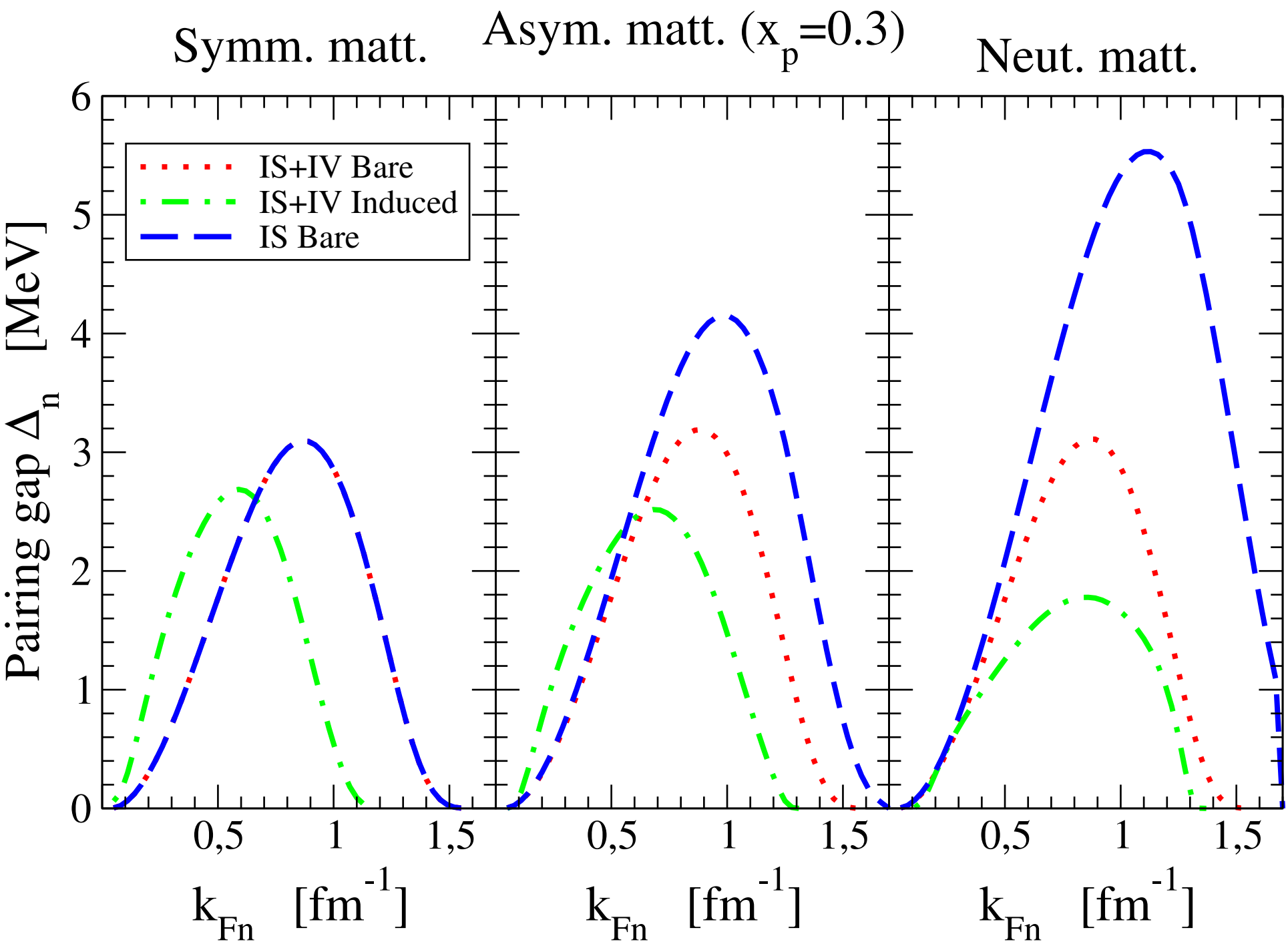
Neutron pairs in semi-magic nuclei

Question 2 :

→ Role of the isospin-dependent term ?




Odd-Even Mass Staggering, in MeV
Ca
Ni
Sn
Pb
$\Delta_n^{(3)}$
Δ_n^{IS}
Δ_n^{IS+IV}
N
N
1
2
3
4
20
30
40
50
60
70
80
100
110
120
130


Symm. matt.
Asym. matt. (x_p=0.3)
Neut. matt.
IS+IV Bare
IS+IV Induced
IS Bare
Pairing gap Δ_n [MeV]
0
1
2
3
4
5
6
0,5
1
1,5
k_{Fn} [fm^{-1}]